VISIT…

know-how. The aircraft industry is geared to pay high prices for plastics with exceptional properties; as high as hundreds of dollars per pound with up to ten-fold cost increases for fabricated products plus additional dollars to conduct continual testing and evaluation to insure safety of aircraft operation.

Medical Product

Plastics continue to make inroads regarding medical applications. Certain plastics have been found to exist in the environment of living tissues. In addition to being of direct aid in medicine, they are also important in medical devices and packaging medical items.

In effect doctors are designers. They are constantly helping design, test and evolve new materials and equipment to augment new and proposed methods of treatment and surgery. Their long, intensive training as basic scientists uniquely suits them to the designer capacity.

Bioplastic

New plastic applications and plastics are continually in use to help in the field of medicine (also biological systems, etc.). They include both mechanical and chemical applications and show the makeup of the field that could be called bioplastics (186). The heart valve that is often used in surgery to correct heart deficiencies was a spectacular contribution to medicine. In order for it to be successful it required first, ingenuity in designing a product that would function as a replacement for the mitral valve and to perform as well as the one replaced long enough to justify the risk involved in the operation. Second, it also required using a material that would function in the highly complex environment of the human circulatory system without being degraded and without causing harm to the circulatory system.

The use of special elastomer plastics (polyurethanes, silicones, etc.) designed expressly for the purpose and tested for years to determine possible adverse in-vivo effects combined with good design resulted in a mechanical device that has been a major lifesaver (29). The role of the plastic designer in an area such as this is one of knowing material limitations, processing problems and of devising test procedures to monitor the performance of the product in the patient as well as in continuous laboratory testing.

Other surgical implants are essentially plastic repair products for worn out parts of the body. It is possible to conceive of major replacements of an entire organ such as a kidney or a heart by combining the plastic skills with tissue regeneration efforts that may extend life. This is used to time the heart action. Extensively used are plastic corrugated, fiber (silicone or TP polyester) braided aortas (24).

While it would be difficult to enumerate all of the efforts in the area of implants where plastics are involved, some of the significant ones are: (1) the implanted pacemaker, (2) the surgical prosthesis devices to replace lost limbs, (3) the use of plastic tubing to support damaged blood vessels, and (4) the work with the portable artificial kidney. The kidney application illustrates an area where more than the mechanical characteristics of the plastics are used. The kidney machine consists of large areas of a semi-permeable membrane, a cellulosic material in some machines, where the kidney toxins are removed from the body fluids by dialysis based on the semi-permeable characteristics of the plastic membrane. A number of other plastics are continually under study for use in this area, but the basic unit is a device to circulate the body fluid through the dialysis device to separate toxic substances from the blood. The mechanical aspects of the problem are minor but do involve supports for the large amount of membrane required.

Bioscience

There are two major areas of application for plastics in bioscience. The plastics make interesting materials to be used for

mechanical implants into all living systems, including animals and plants where they can serve as repair parts or as modifications of the system. The other applications are based on the membrane qualities of plastics that can control such things as the chemical constituents that pass from one part of a system to another, the electrical surface potential in a system, the surface catalytic effect on a system, and in some cases the reaction to specific influences such as toxins or strong radiation.

Chemically active plastics such as the polyelectrolytes have been used to make artificial muscle materials. This is an unusual type of mechanical power device that creates motion by the lengthening and shortening of fibers made from a chemically active plastic by changing the composition of the surrounding liquid medium, either directly or by the use of electrolytic chemical action. Obviously this form of mechanical power generation is no competitor to thermal energy sources, but it is potentially valuable in detector equipment that would be sensitive to the changing composition of a water stream or other environmental flow situation.

By using direct mechanical action from the artificial muscle, it would be possible to produce reliable sensing and control devices without electrical and electronic equipment. Another interesting application would be to drive prosthetic devices where the action would be similar to the muscle reaction in the body. This unusual type of chemically induced motion should be an interesting one to explore for the solution of unusual problems where conventional approaches do not work.

Surgical Product

The most dramatic use of plastics in medicine can be summarized as being in surgery (Table 4-2). Advances in surgery have enhanced the need for providing plastics that can be utilized in replacing or repairing tissues or organs which have been damaged as a result of trauma or disease. The wide

Table 4-2 Example of plastics used in the medical industry

Acrylics	in bone replacement, corneas, adhesives, hemostatic agents, dentures, contact lens, artificial eyeballs.
Cellulose acetate	in nerve regeneration, packaging material.
Formaldehyde-treated polyvinyl alcohol sponge	in support and growth stimulator for blood vessels out-side and into heart muscle, hemostatic agent in repair of liver and kidney wounds, abdominal aortic grafts, vascular shunts, synthetic skin.
Fluorocarbons	in artificial cornea, blood vessels, heart valve coatings, reconstructive surgery, bone substitution.
Polyamide	in vascular implants, syringes, clamps, blood transfusion sets.
Polycarbonates	in syringes, parts of heart-lung machine, baby bottles, containers.
Polyester fiber	in aortic and peripheral artery transplants.
Polyethylene	in tubing, syringes, oxygen tents, repair of incisional hernias, stomach wall support, repair tissue damage, heart valves, contraceptive implants.
Polypropylene	in syringes, sutures, containers.
Polystyrene	in syringes.
Polyurethanes	in plastic surgery, vascular adhesive, bone adhesive.
Polyvinyl chloride	in surgical tubing, blood collection and administration sets, repair of congenital and traumatic facial defects, surgical drapes, ballon type splints, adhesive bandages.
Polyvinyl pyrrolidone	in artificial membranes for filtration of body fluids.
Silicones	in heart valves, tubing, catheters, defoamers in blood oxygenators, urethral valve, plastic surgery, tendon replacement, lubricants, tissue substitutes.

range of forms such film or fiber and mechanical properties available in plastics continues to make them attractive candidates for such uses. However, even though a plastic may possess the desired physical properties, there is no assurance that it may be successfully utilized in the body. Tissue compatibility is a sine qua non for the long-term utilization of a surgical repair material.

The answers to all questions are not known with certainty, and research toward the solution of such problems will require the combined efforts of the plastic chemist and designer with the physician. It is through the efforts of such multidiscipline groups that surgical repair materials of outstanding long-term utility are produced, studied, evaluated, and made available to the patient.

Plastic implants provide a forum for the cross-fertilization of such prepared minds. There is the utilization in tissues of the postenucleation moveable implant and plastic artificial cornea. Use is made of such plastics as PMMAs, silicones, PTFEs, and hydrophilic polymers. This action is related to the implantation of plastic artificial corneas, retinal detachment surgery, glaucoma drainage tubes, repair of bony defects, replacing the vitreous of the eye, and substitution for the eye's crystalline lens. The concept of the incompletely covered foreign body was evolved in connection with the plastic artificial cornea and postenucleation implant. In each case, the plastic (or metal) is exposed to the exterior environment and epithelial cells do not heal like epithelial cells. The semi-exposed implant has been maintained without extrusion for many years. Each of these applications requires plastics with varying properties.

Complex Environment

It is important to recognize that human bodies have extremely complex environments. They could be identified as having the most horrible environmental situation. Reason for this situation is due to the fact that the many different human bodies have different environmental requirements. Thus what can survive in one body usually does not survive in other bodies. This type of reaction requires extensive "prototyping" to ensure that a medical product can survive and meet its requirements in all human bodies.

Dental Product

Most of over six million dentures produced annually in the USA are made of acrylics (PMMAs) that includes full dentures, partial dentures, teeth, denture reliners, fillings and miscellaneous uses. Plastics have been edging into the dental market for over a half century. Even before the introduction of acrylics to the dental profession in 1937, nitrocellulose, phenol-formaldehyde and vinyl plastics were used as denture base materials. Results, however, were not wholly satisfactory because these plastics did not have the proper requisites of dental plastics. Since then, PMMAs have kept their lead as the most useful dental plastics, although many new plastics have appeared and are still being tested. Predominance of PMMAs is not surprising, for they are reasonably strong, have exceptional optical properties, low water absorption and solubility, and excellent dimensional stability. Most denture base materials, therefore, contain PMMA as the main ingredient.

Plastics have not progressed very far as filling materials. About 2 wt% of all fillings are plastics. The low mechanical properties of plastics in comparison with metals limit their application to front teeth where stresses are not so great. It is interesting to note development efforts has taken place in the use of whiskers for reinforcing dental plastic, metal, and ceramic fillings. Some preliminary test results on the addition of randomly distributed chopped, short whiskers to a coating plastic have reversed the previous proportional less of strength with powder additions. Although this is far from theoretical, it is already quite significant in that it allows the addition of pigment for coloring purposes and a restoration of the loss of strength with whisker additions.

Medical Packaging

Plastics are extensively used in medicine to package drugs, ointments, and accessories. Plastics serve to protect medicines, surgical/clinical equipment, medical materials, etc. from contamination and breakage in many ways, from single-service squeeze packs of cough syrup to carrying cases used to ship human eyes between hospital eye banks.

The sophistication of TP processing methods that includes sterilization procedures, has allowed the development of low cost, disposable packages for single-doses of medication, eliminating need for sterilization, etc. Rigid blister packs hold capsules and pills in easily dispensed single servings; semi-rigid and flexible squeeze packs hold single applications of medicines and ointments, etc. Availability of medicines in premeasured single-dose disposable units pleases doctors who previously could only hope that out-patients would dose themselves properly when not supervised.

Biological and Microbial Degradation

Certain plastics such as TP polyesters, polyurethanes, cellulosics, and plasticized PVC can be degraded by microorganisms. It has been observed that enzymes attack non-crystalline regions preferentially. As a result, it has been determined that the resistance of susceptible plastics to microbial degradation is related directly to the degree of crystallinity of these plastics. They remain relatively immune to attack as long as their molecular weight remains high. Most of these plastics are characteristically durable and inert in the presence of microbes.

This stability is important to plastics' long-term performance. However, for some applications only short-term performance is desired before the product is discarded, as in the fast-food and packaging markets. In such cases it is considered advantageous for discarded plastic to degrade when exposed to microbes. There thus exists a requirement to develop or modify plastics possessing the properties required for their service life, but with the capability of degrading in a timely and safe manner, particularly to handle the worldwide waste situation.

The amount of degradation of plastics under the action of bacteria and fungi is of interest because of land-shortage problems in solid-waste management and litter accumulation and other environmental problems on land and sea. The agricultural use of plastics in mulch, films, seeding pots, and binding twines has increased significantly, making biodegradation a desirable feature in plastics, to minimize disposal and soil-pollution problems. With plastics designed to include degradability, the designer could have a monumental problem in ensuring that degradation will occur only after a product's useful life is over.

Other Form of Degradation

Basically degradation is a deleterious change in characteristics such as the chemical structure, physical and mechanical properties, and/or appearance of plastic. A degraded appearance usually means discoloration. Degradation can occur during heat processing. Factors that determine the rate of degradation are: (1) residence time, (2) stock (melt) temperature and distribution of stock temperature, (3) deformation rate and deformation rate distribution, (4) presence of oxygen or other degradation-promoting additive, and (5) presence of antioxidants and other stabilizers.

The deterioration of plastics by biological agents should be distinguished from other forms of plastic degradation. Many other types of plastic degradation may be classified clearly as chemical in nature. In them a deteriorative agent causes a chemical degradative reaction to occur. Chemical bonds are broken or new ones established. Different molecular species of a molecular size smaller or larger than the original desirable species are formed, and these species no longer have the properties for which the original plastic was chosen. Other forms of degradation include landfill, overheating, photochemistry, photodegradable, photooxidation, radiation induced reaction; ultrasonic

degradation, fusion, zymoplastic degradation (substance which, not themselves enzymes, are believed to participate in the formation of enzymes), etc.

This generalization is also true for the degradation caused by heat, electromagnetic radiation, oxygen and ozone, and high-energy nuclear radiation. It is also true for the chemical degradation caused by acids, bases, or other strongly reactive chemical agents. The reaction types include oxidation, ozonization, radical formation, cross-linking, chain scission, and others. The symptoms are described as hardening, embrittlement, softening, cracking, crazing, discoloration, or alteration of specialized properties such as dielectric strength.

The situation with some forms of biological deterioration is somewhat different. Where the agent is macrobiological, as in the case of rodents, insects, and marine borers, the attack is physical in nature, such as by gnawing or boring. The attack is not at the atomic or molecular level. Any breaking of molecular bonds such as in polymer chain shortening is thus accidental. The attack may be said to be at the material's structural level, not the polymer molecule level.

An important item to note is that most commercially used plastics are not single component pure substances. Practically always, the basic polymer itself, rarely if ever a single molecular species, is compounded with other components such as plasticizers, pigments, antioxidants, and other additives. More often than not, then, biological susceptibility is due to the nonpolymer component.

Plastics' deterioration can be classified as either by a microorganism, a macroorganism, or a marine organism (both micro and macro). In the case of microbiological agents, as in fungal and bacterial deterioration, the plastic alterations are caused by chemical attack. This has been demonstrated for the attack on the natural polymer cellulose by fungi through the cellulose enzymes, for many esters, and for many hydrocarbons. It is not yet so clearly proven for the many synthetic polymers, but there is sufficient evidence that may be ascribed to enzyme action as being probably the chief mechanism. Thus, although the medium of attack is biological, the destructive agents are chemical.

Fungal and bacterial deterioration are identified as microbiological and have always caused problems to materials. Fungal attack on plastics has received a great deal of attention beginning with the early days of World War II, when the tropical theaters served to focus attention on the overall problem of materials deterioration.

Microbial deterioration of plastics is intimately involved with the moisture problem, especially with regard to plastics in electronic equipment. For this reason much of the literature treats the two problems together. Furthermore, there is often confusion between the deterioration of the electrical properties of plastics, more often than not a moisture phenomenon, and actual deterioration of the substance of the polymer.

Most investigators agree that in the electronics field moisture accounts for the greater effect. Often, if the moisture problem is solved the fungal aspect is also overcome because of the dependence of organisms on water. Yet not all of this twin problem may be ascribed to moisture, for there are instances where microorganisms are able to destroy the substance of a polymer or attack the nonpolymer constituents of a plastic formulation. Furthermore, as one shifts attention from plastics in electronic equipment to other items where plastics are used, there are clear-cut cases of destruction by fungi. Examples may be found in films, fibers, and coatings.

Dynamic Load Isolator

Thermoplastic elastomer (TPE) components are frequently subjected successfully to dynamic loads where energy and motion controls are required. The products involved range from sporting goods to home appliances to automobiles to buildings to bridges to boats to aircraft to spacecraft. The uses of bonded elastomers for energy and motion control in construction, vehicles, instruments, etc. are extensively used (Chapter 2, **THERMAL EXPANSION AND CONTRACTION, Energy and Motion Control**).

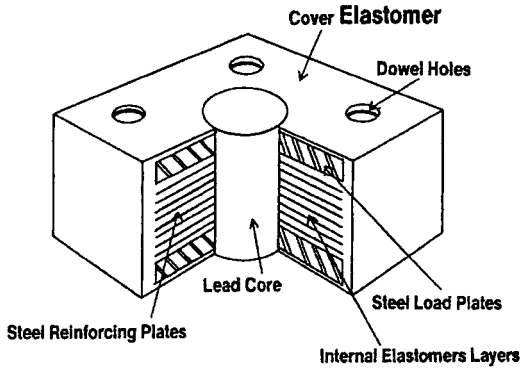

Fig. 4-12(a) Energy and motion control building isolator.

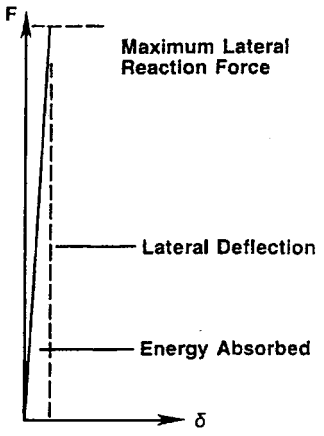

Fig. 4-12(b) Typical load deflection that is characteristic of a marine structure.

An example of this type of energy and motion control device is shown in Fig. 4-12(a). It shows a section through a high-load elastomeric building isolator where the elastomer layers are used to ensure horizontal flexibility. Steel reinforcing plates give rigidity for vertical loads. This isolator resists wind loads elastically without perceptible movement, yields under earthquake loads, and deforms plastically dampening side-to-side vibrations (14, 55).

Anyone in a building, on the highway, on a rapid transit vehicle, or on a ship has a bonded elastomer working for them. In a building, it controls vibration and noise from motors and engines. For rapid transit it supports the rail and the vehicle, thus reducing noise and vibration to adjacent buildings. For ships, bonded elastomers absorb their berthing energies, with single units being as large as 3 m (10 ft.) high and weighing 19 tons. For all these applications, elastomers are used either in shear, compression, tension, torsion, buckling, or a combination of two or more uses, depending on the needs of the specific application (Chapters 6 and 7).

Consider, for example, a berthing vessel that is a structure that has to be designed to withstand the energy developed by the vessel. The more rigid the system, the higher the reactive forces must be to absorb the vessel's kinetic energy. The area under the structure's load as against its deflection response curve (that is, of the energy absorbed) is typical to that shown in Fig. 4-12(b).

For economic reasons, designers typically reduce the mass of a structure, but doing so reduces the lateral reaction forces that the structure can withstand. This happens as the structure is allowed to deflect more or an energy-absorbing device is applied. An elastomer is ideal in such an environment because it will not corrode. Metal components can thus be totally encapsulated and protected against corrosion in an elastomer and then bonded to all-metal surfaces. The elastomer can be used in conditions of shear, compression, or buckling. In examining the load deflection characteristics of these three systems, note that the one that results in the lowest reaction force generally also produces the lowest-cost structure. Figures 4-12(c) to 4-12(e) shows six results that could be obtained, compared to an ideal hydraulic system with 100% energy efficiency.

Filter

Water

One of the major problems facing our civilization is the availability of pure water. The largest source of water located near many cities is the ocean, but the ocean is filled with large amounts of dissolved salts. To recover water from the sea by any of the conventional distillation processes is to date extremely wasteful of energy and costly. However in

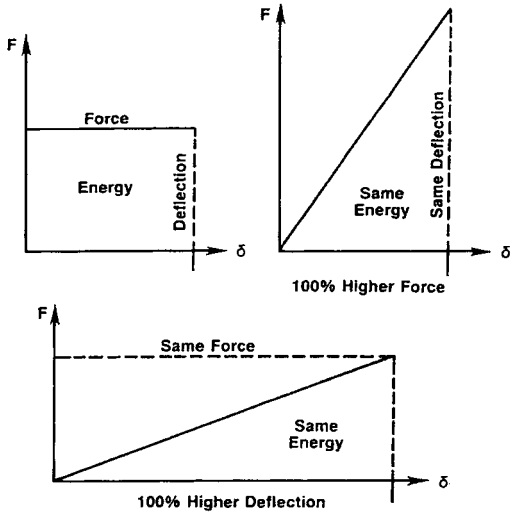

Fig. 4-12(c) Elastomeric shear energy capacity as compared to a 100% efficient curve.

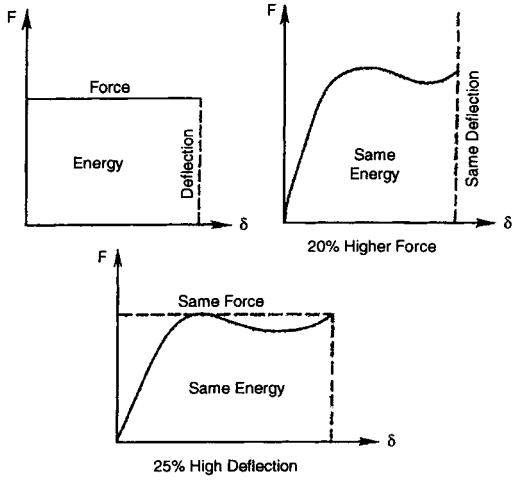

Fig. 4-12(e) Elastomeric buckling energy capacity as compared to a 100% efficient curve.

areas such as the Middle East where fresh water is very scarce, ocean salt water has been filtered by different techniques for many decades.

Plastic membranes are being used in systems that could well pave the way to large-scale water recovery from the sea. The process is reverse osmosis. When water is separated from a concentrated solution of a salt by a semi-permeable membrane, there is a pressure that drives the pure water into the solution for dilution. The driving force is the concentration gradient and it is in the form of a pressure that is related to the difference in the vapor pressure of the water and the vapor pressure of the solution at the temperature at which the process takes place. By applying a pressure greater than the osmotic pressure to a solution, the direction of flow of the water is reversed and pure water is removed from the solution.

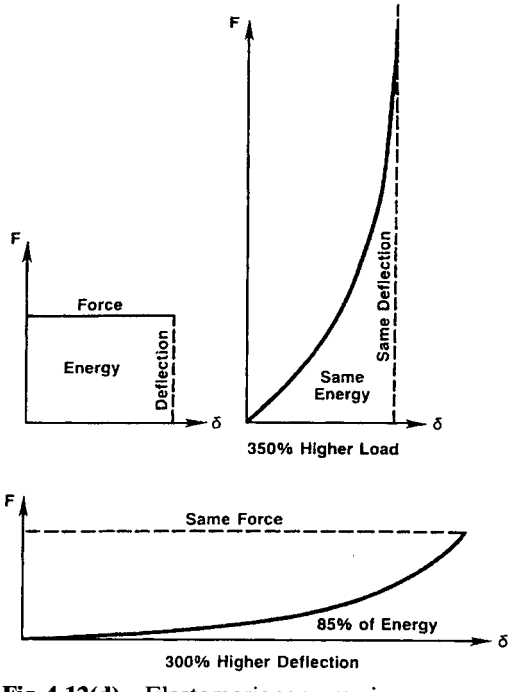

Fig. 4-12(d) Elastomeric compression energy capacity as compared to a 100% efficient curve.

Plastic membrane This is done by the use of a water permeable plastic membrane held deep enough under the sea so that the hydrostatic pressure is greater than the osmotic pressure of the seawater. The water distills out of the solution through the membrane and is pumped to the surface. Large areas of the membranes, mechanically supported to withstand the very high pressures are essential to make the process perform rapidly for the most economical production.

Cellulosic plastics are usually used for the membrane, but any water vapor permeable material is a good possibility, provided the film has good mechanical properties.

Designing the membrane structure for a reverse osmosis plant is a difficult project, particularly in view of the fact that in addition to the pressure exposure, the presence of strong concentrations of dissolved minerals is a hostile environment for plastics.

There have been several very ingenious designs for membrane structures using naturally strong shapes such as arches and tubes reduced to a scale where the amount of surface area for diffusion per unit volume is very high. Other innovations in design and fabrication of these large area membrane structures could easily lead to a significant breakthrough in the availability of an unlimited supply of pure water.

Plastics have had a long history of use in water problems using a special type of plastic material. Ion exchange plastics have been used for many years to remove dissolved materials from water and to make high purity water. The quality of ion exchange treated water is probably better than water purified by any other means. The ion exchange plastics are polyelectrolytes. These plastics are polymers that contain either acid or alkaline side groups capable of reacting with dissolved ions in the water. A standard system used is an acid substituent that forms an insoluble salt with ions such as calcium and strontium and removes them from the water and replaces the mineral ion with hydrogen. The ion exchange plastics can be regenerated by passing another solution through the bed such as a mild mineral acid which removes the attached ions and replaces them with hydrogen again so that the resin can be reused.

Gas

Plastics have a unique contribution to make in exploring new environments. Their applications in space vehicles are well known and are generally of a mechanical nature. Plastics are used extensively in equipment for exploring under the sea. One unique application for plastics used in the sea environment and which is important in other areas that range from packaging to space is in filtering gases. This specific application involves the use of membranes made from special plastics such as silicone compounds that permit dissolved oxygen in seawater to permeate the membrane in one direction and to allow carbon dioxide and carbon monoxide to pass through in the opposite direction.

A large membrane pack of this type will act like an artificial gill, permitting a swimmer to breathe like a fish and remain submerged for much longer periods of time than are possible with scuba equipment. Speculative fiction has man returning to live in the seas, and this type of application may make it possible. Their application in spacecraft is obvious as a part of a continuously recycled air support system. The oxygen permeability of silicone materials is just one example of the selective permeability of plastics.

Liner

Plastics provide different performance requirement in providing protective liners in many different applications such as building foundations, pipe and tank liners containing corrosive liquids, etc. As an example Fig. 4-13 shows an RP stack liner being inspected prior to installation in a 682 ft. high reinforced concrete chimney (background) of the 1,500-megawatt Intermountain Power Project near Delta, Utah (1985).

The liner, of PPG glass fiber, protects the concrete shell from the corrosive gases that occur when sulfur dioxide is produced during coal-fired power generation. Fiber glass-TS polyester RPs provided years of service under these operating conditions. Such liners have been used in this type of application since at least the 1970s. They rapidly became a viable construction material against steel and brick liners. The liners in this Utah project are in canlike sections 45 ft. long and 28 ft. in diameter. The sections were filament wound using 46 to 50 wt % TS polyester-impregnated fiber glass rovings. The completed liner contained about 100 thousand miles, or 11 million pounds of fiber glass roving strands.

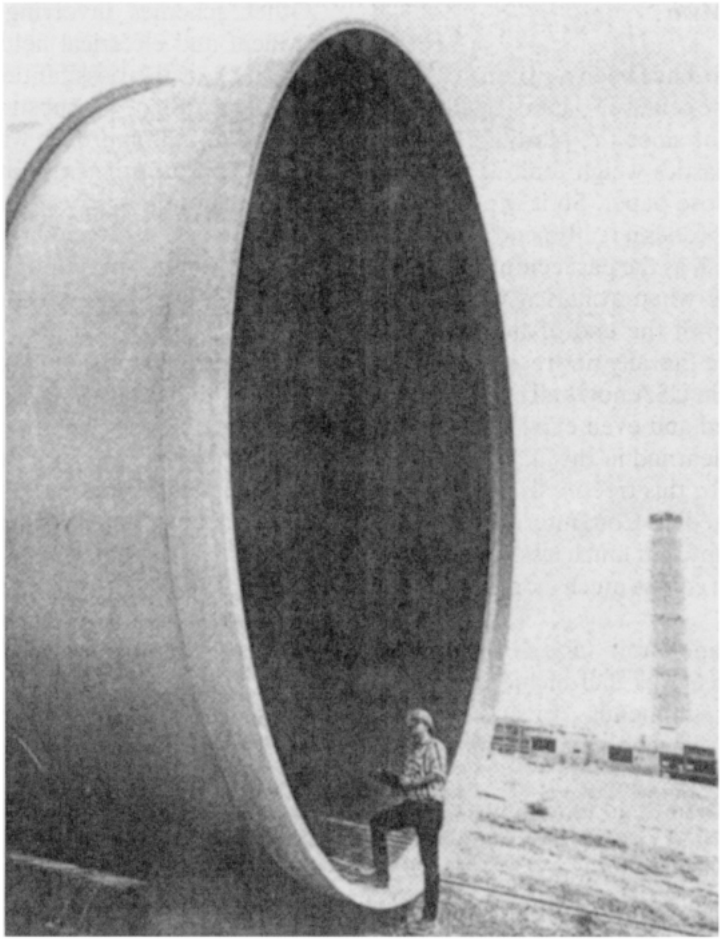

Fig. 4-13 RP stack liner.

Paper and Plastic

One of the problems that face our civilization is the fact that the pressure on natural resources is reported to be hindering progress. Periodically an energy crisis exists that has led to a so-called materials crisis in plastics and even other materials such as cellulose papers. Petroleum is currently the major source of raw materials for most high volume plastics.

Oil and substitute resources such as coal are supposedly in limited supply (although our government reports we have enough coal for the next 250 years that includes its growth in use during that period), and it may well be that another approach to the problem is required. An example is different raw material sources to produce plastics that involve biotechnology (186), more vegetation, etc. Ingenuity in the applications of materials, the province of the designer, and the use of materials that seem to be uniquely modifiable, such as plastics, are needed. Thus the plastics material suppliers are developing renewable resources for the plastics.

We can take as an example worldwide papermaking that now consumes forests at a rate that is supposedly difficult to replace. Unlike the uses for wood, which are generally long-term use goods, most wood pulp paper is used for newspapers, business world, and periodicals or publications that are read and usually discarded, loading our solid waste disposal system and adding mountains to our trash.

Save the Tree Myth

Plastic papers have been developed as substitutes for these cellulose papers, but the economics are poor since the plastics are more costly. Also plastics weigh tend to be more than the cellulose paper. So it is possible to save the forests (does it really need it since it is easy to replenish as the past century proved). Did you know when America was discovered and up until the end of the 19th century there were literally no trees when compared to those in USA now and any depletion can be replaced and even expanded (as one knows who is learned in this field). Another factor related to this tree myth is that when the world started its Computerized World it was said by many that much less paper would be required. Of course much more is used and required.

Synthetic paper now targets high-priced specialty applications that include beverage labels, restaurant menus, drivers' licenses, recipe books, instruction manuals, maps, and book jackets.

The justification to go to a higher cost paper material would be part of a system where the paper is continuously reused. By using a material which has erasable printing generated by the remote printing terminal, the newspaper or periodical could be printed at its destination.

Plastics can be used to make erasable printing media by a number of different techniques. Photo changing dyes could be incorporated into the structure of the plastics. The printer could change the dye to the colored form to read, and the material can be bleached with another unit that would reverse the photo coloring process. An ionic type plastic can be incorporated into the plastics and used to color the printed area by the use of an indicator type reaction with an organic acid or base. Another method would be to use a thermal printer in conjunction with liquid crystal type materials that would alter the state of the liquid crystals in the printed areas. Applying heat and electrical fields to the printed sheet would erase the printing.

Other schemes involving dichroic dyes with heat and electrical fields are also possible. Each of the possibilities could use the plastic structure of the substrates, its durability, or both. This approach would recycle the material for carrying the printed messages at the point of use, eliminating handling and distribution costs, and would require a fraction of the enormous amount of paper now consumed in delivering news and other literary material. The newspaper or periodical would have the familiar size and appearance and would present little change to the reader. The convenience of real on time home delivery and other built in aspects of the system would make it a useful successor to the present one. (This is just a point to discuss and amuse oneself but it could happen.)

Union Carbide Corp produced the first of the synthetic papers in the late 1960s. Since that time other examples of synthetic papers include DuPont's Tyvek nonwoven paper and Van Leer's Valeron cross-laminated film. This market is now dominated by a few large, worldwide ventures with proprietary processing techniques that extend the use of single and multilayer extruded blown film or cast film.

Developing Idea

Polyelectrolytes such as the ion exchange plastics form an interesting group of materials because of their ability to interact with water solutions. They have been used in medical applications involving the removal of heavy metal ions from the human body. They can be used to interact with external electric fields and change their physical properties drastically as is illustrated by the fact that some electrically active liquid crystals are polyelectrolytes of low molecular weight.

Another application for polyelectrolyte materials is in the forming plastics with unusual physical properties with regard to adhesion. The incorporation of small amounts of organic acid materials into polyolefin structures results in materials that have excellent adhesion to metals, paper, glass, and a variety

of other materials. In addition, the materials with electrolytic structures can have a metal ion incorporated into the structure resulting in the formation of the ionomer type of resin that has much better mechanical properties than the basic polymer material.

Several other interesting material developments that may be useful to the designer in the future will be mentioned. Since one key step in any design is the material selection, an important aspect of the designer's responsibility is to be familiar with the range of material possibilities. Plastics interact with high energy radiation by giving bursts of visible light. This can be made selective for particular types of radiation and the effect has been used to make materials for scintillation counters to measure gamma radiation and particle streams such as alpha particles and beta rays.

The ability of some plastic systems to do this may be useful in schemes for handling the radiation output of nuclear devices, including the radiation from the fusion power machines under development. Obviously the application is not for shielding, which the heavy metals do much better, but rather for an energy level reduction system that would convert the high energy radiation to forms which would be more useful in power distribution.

There has been a great deal of interesting work done recently in attaching active enzyme materials to plastics substrates to convert simple organic molecules into the more complex forms used in biological processes. This technique makes available a catalyst bed capable of doing large-scale synthesis of materials such as proteins and carbohydrates that are essential to life processes. With a major food crisis always looming as a result of the rapidly increasing population of the world, it may be necessary to revive the possibility of synthetic food production even though this subject is very controversial. Since farm land is being depleted and recurring drought conditions reduce food supplies, it is likely that synthetic food will be a necessary supplement. The selective action of enzyme membranes may be a way to approach the food synthesis problem.

Joining and Assembling

Joining of a plastic product to another product composed of the same or a different plastic material, as well as other materials such as metal, is often necessary when: (1) the finished assembly is too complex or large to fabricate in one piece or (2) disassembly and re-assembly is necessary.

The success of a specific technique will depend on whether, as a by-product of the technique, sizable stress levels in the plastic product may result. Guarding against potential stresses in the assembly is a very important aspect of complete product design. There are many techniques that provide assembling all kinds of products. Each have technical and/or cost advantages and limitations. Examples of a few are reviewed in this section with more information in Chapter 3, **BASIC FEATURE and FEATURE INFLUENCING PERFORMANCE.**

Molded-In Insert

Plastics perform satisfactorily with metal-molded inserts and expansion-type inserts. To minimize the stresses created at the metal-plastic interface by the differences in thermal expansion rates for molded-in inserts, observe the following safeguards: (1) the design permitting, use plain, smooth inserts; (2) use simple pull-out and torque-retention grooves when high torque and pull-out retention are required; (3) if a knurled insert is used, keep the size of the knurls to a minimum, remove all sharp comers, and round the hidden end of the insert and keep the knurled section away from products' edges (Fig. 4-14), (4) keep the inserts clean, removing chemicals such as oil from them; (5) use high side of mold temperatures to reduce thermal stresses, such as for commodity plastics at 82 to 105°C (180 to 220°F); and (6) provide sufficient material around the insert.

Use the following guidelines for material thicknesses around inserts: with aluminum use 0.8 times the outer radius of the insert, with brass use 0.9 times it, and in steel